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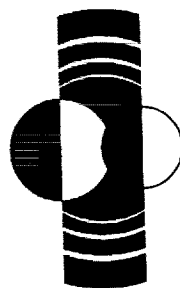
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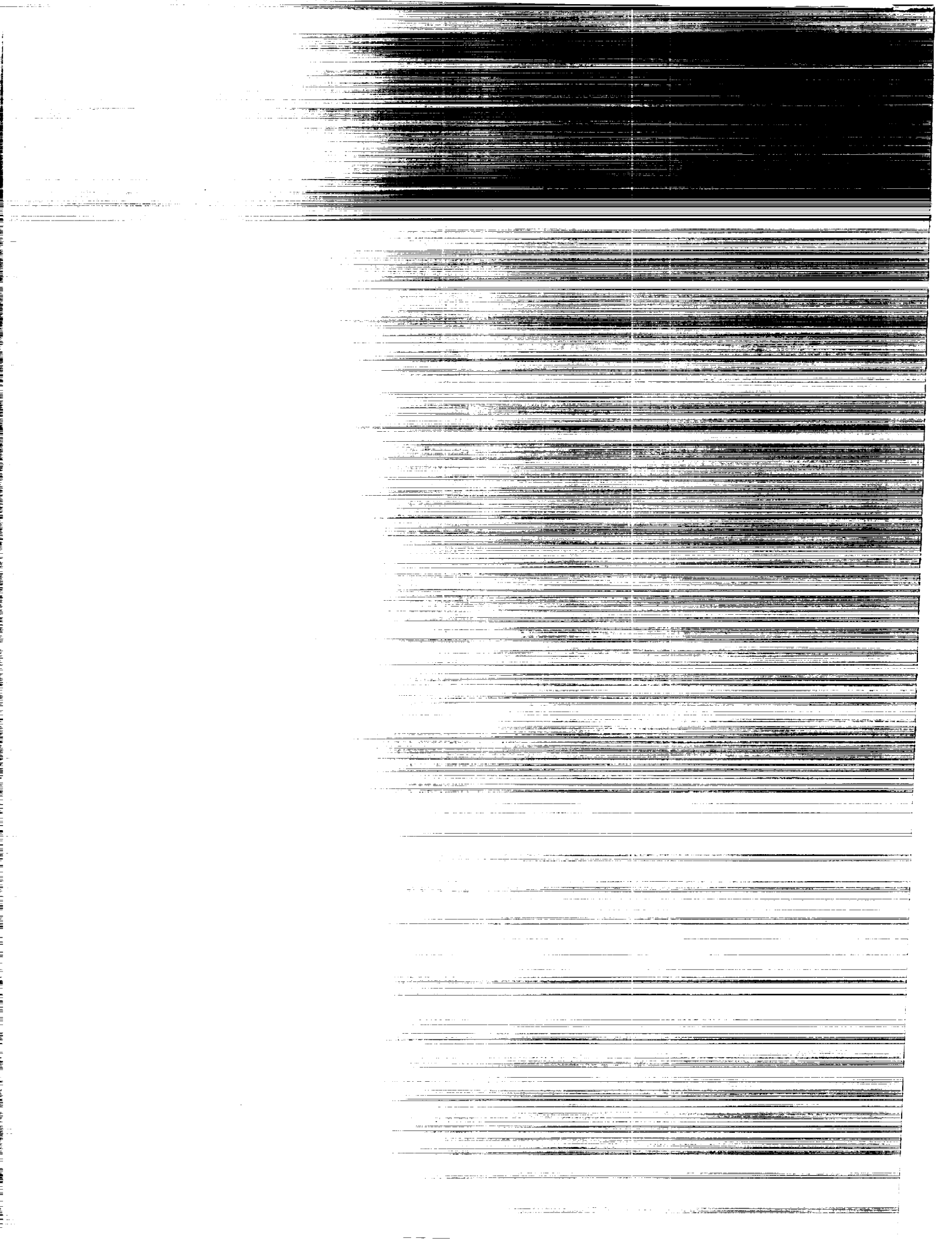
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Mars Surface Mission Workshop



October 4-5, 1997
Lunar and Planetary Institute



MARS SURFACE MISSION WORKSHOP

Edited by

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Held at
Houston, Texas

October 4–5, 1997

Sponsored by
National Aeronautics and Space Administration
Lunar and Planetary Institute

Lunar and Planetary Institute 3600 Bay Area Boulevard Houston TX 77058-1113

LPI Contribution No. 934

Compiled in 1998 by
LUNAR AND PLANETARY INSTITUTE

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Duke M. B. (1998) *Mars Surface Mission Workshop*, LPI Contribution No. 934, Lunar and Planetary Institute, Houston. 11 pp.

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Preface

A workshop was held at the Lunar and Planetary Institute on September 4–5, 1997, to address the surface elements of the Mars Reference Mission now being reviewed by NASA. The workshop considered the current reference mission and addressed the types of activities that would be expected for science and resource exploration and facilities operations. A set of activities was defined that can be used to construct “vignettes” of the surface mission. These vignettes can form the basis for describing the importance of the surface mission, for illustrating aspects of the surface mission, and for allowing others to extend and revise these initial ideas. The topic is rich with opportunities for additional conceptualization. It is recommended that NASA consider supporting university design teams to conduct further analysis of the possibilities.

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Workshop Summary

INTRODUCTION AND BACKGROUND

The NASA Reference Mission for the Human Exploration of Mars was assembled in 1993–1994 through a series of workshops and work performed by an integrated team of NASA engineers and scientists, led by the Exploration Program Office at the Johnson Space Center in Houston. The objectives of the Reference Mission were to break the then-existing paradigms for Mars exploration in a manner that could achieve substantially lower costs over previous scenarios. In the process of developing the Reference Mission, it was decided that the appropriate approach was to start with the “Surface Mission,” that set of capabilities and activities on the surface of Mars that would address the fundamental scientific objectives as well as the activities needed to support the explorers. This led to a Reference Mission that differed from previous approaches in a variety of ways, but, most importantly, emphasized long stay times on the surface, long-range exploration capability from the outpost, and robust surface systems. It was also possible to significantly reduce the cost compared to previous missions, because the robust surface infrastructure included the capability of producing propellant on the surface for the return trip home as well as for surface exploration vehicles. This infrastructure also allowed effective utilization of a split mission strategy, in which systems and consumables could be emplaced and tested before the crew left Earth.

For the initial version of the Reference Mission, a relatively simple set of surface mission capabilities was assumed, which included the capability to land and complete the assembly of outpost elements, explore the near-vicinity of the outpost using space suits, operate teleoperated vehicles at great distance from the outpost, and conduct human exploration beyond the near-vicinity of the outpost using a pressurized rover/habitat vehicle. Neither the detailed exploration tasks nor the detailed support tasks were developed in any great detail.

The Reference Mission is now being published and discussed widely, and updates, modifications, and extensions of it are actively being developed. NASA is giving a high priority to that effort because of renewed interest in Mars exploration, manifested in a set of robotic missions that, starting in the summer of 1997, will result in the launch of two missions every 26 months until perhaps 2009. Some time in the middle of the first decade of the 21st century, NASA expects to have the information needed to decide on the nature and timing of the first human expeditions to Mars. Thus, the Reference Mission for human exploration of Mars serves as a mechanism for better understanding the nature of those first human expeditions, as well as providing guidance for the selection of experiments to be carried on the robotic missions.

In that regard, it is important to define the surface mission to a greater level of detail. A better understanding of the surface mission will have many ramifications in designing the Mars program. It will (1) provide the basis for determining the surface payloads; (2) be the basis for identification of crew number, skills, and training; (3) form the basis for visualizations and realistic simulations of Mars missions; and (4) help identify experiments to be carried on robotic missions.

This workshop represents an initial step in the process of further developing the surface mission. It was undertaken by a group consisting primarily of Mars science experts. They reviewed the existing Mars Reference Mission and, after considering the objectives of Mars exploration, developed a set of activities that represent the way in which humans and systems would function on Mars to conduct the first human exploration of the planet. Inherent in this analysis is the expectation and belief that the exploration and development of human capability on Mars will require that humans go there, and that robotic exploration alone will neither be able to conduct the scientific exploration to an effective level of problem solution, nor conduct those experiments that will allow humans to determine whether it is prudent and practical for people to eventually inhabit Mars.

The workshop concluded that there were two types of activities that could be represented and divided into two working groups that independently addressed (1) science and resources and (2) living and working on Mars.

Science and Resources

This set of activities responds to the issues raised by our desire to understand the significance of Mars in terms of the origin and evolution of the universe and the origin and evolution of life in the universe, as well as to use the natural resources of the planet for human benefit. NASA has used a three-pronged approach to describe the scientific exploration of Mars: the search for evidence of life or its precursors; the study of the climate evolution of Mars; and the understanding of Mars’ physical development leading to the availability of resources useful to humans. Understanding the distribution and history of water is an essential element in this exploration. Currently, the search for evidence of past life on Mars has received a great deal of attention, following reports of possible chemical and morphological evidence of life found in meteorites from Mars.

As the search for life cannot be separated from an understanding of the geological and climatological history of the planet, a unified approach is possible. A strategy has been advanced for using the robotic missions to gain additional data on a planetary scale and a local scale for a few places, which could lead to exploration by humans at scales not

readily achievable by robots. These scales include regional exploration scales, which are beyond the capacity of robotic devices under teleoperation control from Earth, and a microscopic scale, which requires intensive sample selection and processing only achievable by humans.

Living and Working on Mars

This topic involves a set of individual and group activities required to achieve long-duration stays on Mars. These include system operations, communications, maintenance, health maintenance, and personal activities including recreation. Most of these activities are required to assure the effective completion of the exploration objectives. Some are related to the interest in defining future capabilities, tasks, and opportunities for people on Mars, and some are simply expressions of human needs transferred to a totally new, isolated, and hazardous environment.

The set of activities identified, though not necessarily complete, was briefly described, and a subset developed that appears to be the most promising for further elaboration and illustration. It is hoped that the NASA Exploration Program will use this as a starting point for developing a more explicit program of study, technology identification and development, robotic mission experiment definition, and operational planning for Mars expeditions. Needs that could lead to future organized effort have been noted.

SCIENCE AND RESOURCES

The principal scientific objectives for Mars exploration include the search for evidence of ancient or extant life, the evolution of climate, the geological evolution of the planet, and the resulting inventory of its natural resources.

The Search for Evidence of Ancient or Extant Life

Since the Reference Mission was developed three years ago, new scientific discoveries have revived interest in these issues, which had been discounted as a focal point for Mars exploration since the essentially negative results of the 1976 Viking missions. The first new discovery was the chemical and morphological features of a martian meteorite that have been interpreted to represent evidence of ancient life. At the same time, it has been discovered that organisms are living at depths of several kilometers in the Earth, in environments such as flood basalt sequences, where no one would have thought life could survive. It has been known previously that water was present in the early history of Mars and that environments in which life could have arisen probably existed, but these new findings add fuel to the concept that life indeed arose on Mars and that, once developed, it could have persisted in isolated environments to the present day. Water is an essential component on Earth, and the environments

deduced for the ancient features in the martian meteorites also are water-bearing. The discovery of ancient life on Mars would have profound implications for the evolution of life on planetary surfaces and for the existence of life beyond the solar system. The discovery of existing life would allow detailed study of a totally different biota from that found on Earth, with the potential to unlock additional keys to the problem of the origin and evolution of life forms.

The strategy for finding evidence for ancient life on Mars involves finding "life-likely" paleoenvironments, places where it can be inferred that liquid water existed, either from morphological (shorelines) or mineralogical (deposits of evaporite minerals) evidence. Once found, these environments would be characterized in detail—their geological context and age, their horizontal and vertical extent, the variability of mineralogy and composition studied, and evidence of organic remnants, organic marker minerals (inorganic minerals deposited by organisms), and fossils would be sought. The past environment could be reconstructed from these data. It might be possible to determine the original composition and temperature of the water from appropriate samples. If fossils were found, it might be possible to revive organisms, which are known on Earth to be able to survive long periods (up to 3 m.y.) of dormancy. Such studies require intensive local field investigations, once appropriate areas have been located.

The strategy for finding evidence of extant life is based on finding environments in which liquid water exists. The two major possibilities are (1) liquid water or brine environments underlying permafrost have made surface layers impermeable to gas leakage from the warmer subsurface, and (2) in areas surrounding recent igneous or volcanic features, hydrothermal fluids may exist. These are known on Earth to be conducive to the support of organisms that use chemical energy rather than light as their source of energy.

The Evolution of Climate

Mars' climate has changed with time from one in which liquid water could exist on the surface, implying higher atmospheric pressures and warmer temperatures, to its current environment in which liquid water cannot exist and temperatures are cold. Questions of the reasons for this climatic change might be resolved if the atmospheric composition could be deduced through time. This may be possible through the study of the mineralogy and chemistry of sedimentary rocks, weathered rock products, and trapped gases that may exist in a variety of environments on Mars, as well as through the study of the current atmosphere and the processes by which it gains or loses atmospheric constituents. One hypothesis is that the atmospheric evolution is associated with the internal thermal evolution of the planet, in which case Mars may represent an accelerated example, compared to Earth, of what happens to a planet when it cools internally.

This of course would have considerable implications for the future evolution of Earth's climate.

The strategy for studying the evolution of the martian climate involves several major thrusts:

Search for carbonates. This is necessary to evaluate the C cycle and inventory of the planet as a function of time. The isotopic composition of C can be utilized to deduce the environment as well as the temperatures of deposition of the minerals.

Search for water. The amount of water that could have been in the atmosphere is unknown, as is its current location. Geological and geophysical searches for ground ice, ground-water, hydrated minerals, and weathering products, as well as their detailed analysis, will contribute to these studies.

Search for evaporites. When rocks stand in water, they slowly dissolve. When the water evaporates, new classes of minerals, known as evaporites, are formed, such as gypsum and halite (NaCl). Field work would search for places where such minerals exist and the samples would be subjected to mineralogical, chemical, and isotopic analysis to determine the environments in which they formed, including the temperatures of formation and the composition of the brines from which they were formed.

Search for weathering products. Weathering products of a variety of ages would be sought to establish particularly the isotopic composition of water, O, and C as a function of time. This would require finding ancient weathered rocks that had subsequently been protected from further weathering.

Regolith characterization. The regolith has been formed by a complex interaction of aeolian, aqueous, and impact phenomena. Its depth, stratigraphy, grain size, mineralogy, and petrographic properties can be interpreted in terms of the erosional history of the planet as well as its geological history.

Exploration of erosional and depositional features, i.e., valley networks and crater lakes. These features represent the morphological expression of the past existence of liquid water on the planet. It will be important to explore these features and determine the time history of events and processes that produced the observed features.

Study of current atmosphere. This would involve study of the current atmosphere, its reactivity with surface materials, and the loss mechanisms that control the abundances of gas molecules in the atmosphere. The study of meteorology addresses the current dynamics of the atmosphere, which may provide clues to past atmospheric activity.

The Geological Evolution of the Planet and the Resulting Inventory of Its Natural Resources

This includes Mars' volcanic and impact history and the history of interaction of the surface and atmosphere. Scientifically, this is important in building evolutionary planetary

models. On Mars, however, humans may utilize the water resources of the planet, whether it is in the atmosphere, in mineralogical combination with rocky materials, or as ice in polar caps or permafrost; they may use the mineral resources to extract life-support materials, metals, ceramics, and rare materials; and they may utilize its innate energy environment, internal or from the sun, to support human activity. The availability of concentrated resources for human use will be defined by Mars' geological history, and their development will be guided by our understanding of the planet's geological evolution.

The focus areas for resources include:

Mineral constitution. Understanding the mineral constitution of the surface of Mars would include understanding the processes by which this mineralogy was formed, be it volcanic, weathering, aqueous, or impact in origin. Of particular importance to the topic of usable resources is the exploration of hydrothermal and lacustrine deposits. In both of these environments, the interaction of water with rock may have concentrated otherwise rare elements. Mars is likely to be more complex than the Moon because of the interaction of permafrost during meteorite impact. This may have produced local, temporary concentrations of water which could have redistributed elements. In lacustrine deposits, the evaporation of large amounts of salty water could have left usable amounts of materials such as Na and K chloride and B compounds, which could eventually be useful technologically. Field exploration and sample analysis will be the principal tools in this undertaking.

Water exploration. Water may exist locally at depth as permafrost or below permafrost as brines. The earliest form of exploration for water is likely to be geophysical sounding rather than drilling. However, if subsurface data indicate the possibility of solid or liquid water, it will be of great interest as a resource for supporting human activities. If liquid water is found, its sampling will have to be done very carefully, for it may harbor indigenous life forms, raising the possibility that the environment could be contaminated by human activity or that humans could carry active organisms into their habitats. Water as a resource occurs also in the atmosphere and probably as bound water in regolith minerals.

Energy exploration. Geological exploration for energy on Mars may target warm areas where geothermal energy may be developed or pressurized aquifers that can develop artesian pressure. Solar energy is likely to be used directly by human explorers, particularly in areas remote from central power stations. And indirect solar energy, in the form of wind energy, has been suggested as a development possibility.

SCIENCE DISCIPLINES AND ACTIVITIES

The three principal science objectives have been recognized as essential elements in the current Mars exploration strategy, with a major emphasis on the search for ancient

life. This will be carried out through orbital remote sensing, *in situ* analysis, and the return of samples to Earth for detailed study. The scientific disciplines involved include geology, geophysics, climate, meteorology, and exobiology. These scientific disciplines are expected to carry through to the phase of Mars exploration where humans will conduct *in situ* investigations of the planet.

It is not likely that the answers to scientific questions in these areas will be resolved satisfactorily by robotic missions prior to the time at which human exploration is possible and financially realistic. In order to examine and arrange the types of activities that would be undertaken by humans in these scientific disciplines, it is in principle necessary to know what has been discovered by the robotic missions that precede human exploration. However, the fundamental capabilities of humans, compared to those of robotic explorers, provide a good basis for determining the types of activities that would be carried out by people. Therefore, a matrix was constructed that compiles some projections of activities achievable throughout the human phase of Mars exploration (Table 1).

SCIENCE AND TECHNOLOGY

In terms of activities to support the themes of resources, it is difficult to separate the specific activities that are required from the technological development of the tools to allow the resources to be utilized, once found. The science and resources subgroup identified a set of activities that are related to geological exploration, but have additional technological ramifications.

Cartography

Map-making. Astronauts exploring Mars would be equipped with very good maps of the surface, at spatial resolutions of a few tens of meters to a hundred meters. These maps will be adequate for general planning, but are likely to be insufficient to be highly useful to crew members doing surface traverses or field investigations, where a resolution of 1 m or less would generally be desired. There are several ways in which such images could be obtained concurrently with field work. Recoverable rockets, fueled with propellant

TABLE 1. Types of activities associated with scientific themes.

Science Activity	Indoor	Outdoor	Robotic
Geology	Rock analysis	Field geology	Sample collection
	Thin sections	Mapping	Aerial reconnaissance
	Scanning electron microscope	Geomorphology	(balloons, airplanes)
	Petrographic microscope	Stratigraphy	Local high-resolution maps
	Geochemistry, age dating	Mineralogy	Multispectral mapping
	Sample storage/curation	Drilling (deep, shallow)	Elemental sniffers
	Teleoperate rovers	Trenching	
Geophysics	Displays	Active seismic	Local regional geophysical network (seismic, magnetometer)
	Data analysis	Electromagnetic sounding	
	System operations	Geophysical station emplacement	
	Time base		
	Paleomagnetic laboratory		
Climate	Evolved gas analyzer, mass spectrometer	Geology/sample collection	
		Volatile inventory (H ₂ O, CO ₂ , etc.)	
		Hydrologic history	
		Paleoclimate	
		Recent/cyclic changes	
Meteorology	Display	Outpost meteorology station	Regional network
	Atmosphere composition	Tethered balloon	
		Short-term focused experiments (dust storms, atmosphere structure, diurnal, annual variations)	
Exobiology			
	<i>Extant</i>	Explore promising environments	
	Culture samples	Hydrothermal areas	
	Staining, biochemical analysis	Deep subsurface drilling	
	Planetary quarantine		
	Back-contamination controls		
<i>Fossils</i>	Rock analysis (see geology)	Field work (see geology)	Robotic field work (see geology)

made at the outpost, could carry cameras high above the traverse site; free-flying or tethered balloons could gather multispectral imagery from altitudes of a few kilometers, or aircraft could be utilized. Obtaining these data would lead to the need to reduce and process stereoscopic images, probably at the outpost.

Geodetic control. A geodetic benchmark system will be necessary to tie the altitude and locations of points on the surface to one another and to a global grid that now exists. This might be integrated with a surface navigation system.

Surveying and plane-table mapping. Very high resolution maps may be needed at sites of high scientific interest. It will also be necessary to determine accurately the location and orientation of emplaced meteorological and geophysical stations.

Resource Extraction and Utilization

Atmospheric extraction. It is currently assumed in the Reference Mission that O_2 would be obtained from the atmosphere by reduction of CO_2 . It is also possible that condensation of water from the atmosphere may prove to be feasible. The establishment of these capabilities will be done robotically; however, maintenance, adjustment, or repair may be required.

Mining engineering. Several promising targets are available for developing useful resources. These should be considered for demonstration experiments on robotic or early human missions.

Extracting water from the soil. Viking experiments suggested that there may be about 1% of bound water in the regolith. This may become an attractive candidate for local production of water.

Salts. The leaching of salts from the soil should be straightforward. At this time it is not certain what the soluble elements are in martian soil; however, the first returned sample should clear up any uncertainties. It is known that S and Cl are enriched in the martian dust. On Earth, some of the more useful compounds that are present in soluble form in the soil are salt (NaCl), gypsum (calcium sulfate), zeolites, and B compounds.

Iron. The soil of Mars is known to be rich in Fe oxides, including magnetic forms. Its concentration into a feedstock should not be difficult. Carbon or CO can be produced from the atmosphere by the same systems that produce methane and O_2 for propellant. Thus, the basic constituents needed by an Fe smelter exist. Sheets of metal may find various practical uses for a long-term outpost. Possibly the first use would be in the construction of an external, unpressurized storage shed for rock samples.

Subsurface Exploration

The exploration of the subsurface is another challenging opportunity for geological exploration. To some extent, the

natural excavation performed by impact craters or in eroded canyon walls can provide the three-dimensional information; however, the craters or outcrops will not always be in places that are accessible or in the units that are important for study. Both geophysical techniques such as active seismic (where explosions are set off to create subsurface waves) and ground-penetrating radar, as well as controlled excavation, may be utilized. For near-surface investigations, trenching or digging with robotic systems may be preferable. For deeper investigation, a 10–30-m drill may be sufficient to penetrate the uppermost weathered and modified surficial material in most places. Such a drill should best be portable, because it would typically be used in localized areas where surface observations suggest that it would be productive to drill. Yet deeper drilling may be required to search for ice, groundwater, or steam and to sample hydrothermal deposits. The use of explosives in some cases may be justified. This might be the case where the object primarily was the hole, rather than the observations that could be made in it. For example, a requirement may exist for a rapid means to excavate a crater to serve as radiation shielding against a solar flare for a crew at some distance from the outpost.

Construction Materials

There are a number of materials that could be used for construction materials directly or with fairly simple processing. They should be considered for demonstration experiments on robotic or early human missions.

Brick production. This might be quite comparable to brick production on Earth, done in an atmospherically controlled kiln that bakes surface clay that has been saturated with water.

Concrete. The materials from which cement can be made (e.g., Ca carbonate) are likely to be present in the surface at some places. Although concrete would have to be cured in a controlled environment, methods for doing that have been proposed for the Moon.

Sintering. Heating up the surface dust to the point where it first starts melting (possibly as low as 800°C for Mars surface dust) can produce glassy materials with sufficient strength to form structural building blocks.

Rammed "earth." It may be that simply compacting soil can provide a material for some uses, such as radiation shielding, that need to be transported and erected easily. Techniques developed for this may also be applicable to stabilizing slopes in trenches.

Construction Applications

Some construction tasks for which these materials may be of interest include road construction, building construction, and instrument site preparation.

Road construction. In high-traffic lanes between surface facilities, it may be desirable to construct roadways. This

may range from simply specifying that vehicles continue to follow a particular path between two locations, *de facto* developing a pathway, to places where it is prudent and feasible to remove surface obstacles. This may not be something that would be used during early Mars missions, but if the outpost continued to develop, it could be quite useful and could be readily demonstrated on early missions.

Building construction. There are various ways in which materials produced on Mars could be used at early stages of an outpost program. Two suggested are (1) radiation shelters and (2) storage sheds or garages. If it were possible to simply produce and erect structures, this could be a good demonstration of the effectiveness of humans at the Mars outpost. Ultimately, much larger structures could be required at a permanent Mars outpost.

Instrument site preparation. An alternative requirement for similar types of surface construction capabilities is that of preparing the site with sensitive scientific instruments, such as seismometers. These instruments would likely be emplaced in the vicinity of the outpost, but at enough distance that the outpost activities would not affect their operation. The activities involved could include grading a level site, excavation to bury sensors; construction of windbreaks or other shelters; and drilling or digging to bedrock to firmly connect (couple) the seismometers to the interior.

LIVING AND WORKING ON MARS

The human operations that were chosen to characterize the activities to be undertaken at the Mars outpost include (1) base setup, (2) base maintenance, (3) biological life-support system operations, (4) pressurized rover operations, and (5) predeparture operations.

Current experience on the space shuttle suggests a distribution of available crew hours as shown in Fig. 1.

There is concern that on very long missions, the amount of time spent on maintenance and housekeeping activities will be greater, as is currently the case on the Mir Space Station, which is well past its design lifetime. It is generally thought that time will be organized into daily patterns, with one shift operations, one or two days off on weekends, etc. Crew recreation was recognized as a significant consideration and several possibilities were mentioned for crew recreational activities.

Base Setup

Activities associated with setting up the base include six areas:

1. *Deployment of the power system.* The power system will have been predeployed to Mars and will have been installed robotically. It is envisioned that a robotic vehicle would extract the nuclear power system from the cargo lander, drive it 1–2 km from the outpost, running an electrical cable, and place it in a location where radiation hazards will be

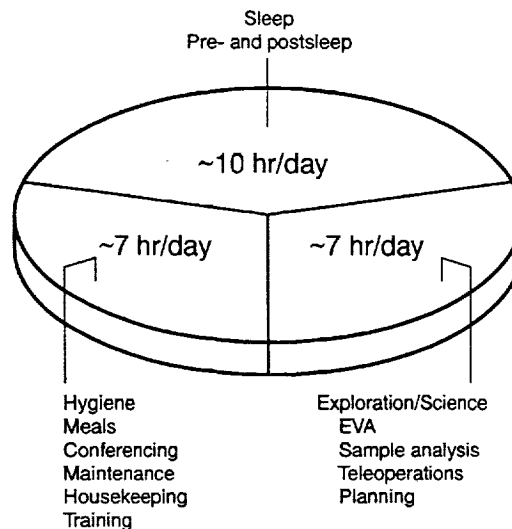


Fig. 1. Possible distribution of available crew hours for Mars exploration. It is anticipated that a six-day work week would be the norm for Mars crews.

minimized. When the crew arrives, the system will be operational, but the crew will have to connect it to their habitat within the first day of crew operations.

2. *Deployment of the communications system.*

3. *Deployment of the ISRU system.* This will be done robotically before the crew arrives; the crew, however will undoubtedly inspect and test the ISRU system when they arrive. It may be desirable to move the facility, in order to increase its effectiveness or remove it from the immediate vicinity of the ascent vehicle. It may be necessary to connect additional storage tanks.

4. *Setup of the inflatable lab/hab structure.* This structure is expected to provide space for a greenhouse, which will have to be set up. It will also provide additional space for crew members.

5. *Deployment of the science rovers (telerobotic), pressurized and unpressurized crew rovers.*

6. *Relocation of surface elements.* It may be necessary to move the habitat from the spot where it landed to a better location.

Base Maintenance

Maintenance will be an ongoing activity and will include several areas:

1. *Walkaround inspections of the facility.*
2. *Space suit maintenance and cleaning.*
3. *Robotic rover TV surveys of the facility.*
4. *Change out of external elements (e.g., filters).*
5. *Maintenance and repair of internal elements.*

It is anticipated that some level of machine shop and fabrication capability will be required on board. This is an im-

portant area of mission design because, due to the length and isolation of the mission, the crew will have to be responsible for the maintenance of the system and unexpected failures can become hazardous to the crew or reduce the effectiveness of its mission. At a more mature stage in the Reference Mission scenario, it may become possible to rework used materials into utilitarian items, or to manufacture replacement hardware using natural martian resources.

Biological Life Support System

This system is an element of the operational system as well as a scientific test bed. The operation of the system will include setting up the system in the inflatable module, planting crops, maintaining the environmental conditions during the growth of plants, and harvesting crops. It is anticipated that experiments will be carried out in which martian materials are inserted into the life-support system to determine their utility.

Rover Operations

These will consist of operating the pressurized rover and its systems. The rover will be a miniature habitat on wheels and will have to be given the care and maintenance provided to a habitat, as well as to its transportation system. The pressurized rover will have the capability of acquiring samples without the crew emerging from the habitat (robotic arms/air locks), which adds another system not planned for the main habitat. When the rover is housed at the outpost, there is likely to be routine maintenance to be performed. It may be desirable to construct shelters for mobility vehicles and, at some stage, provide a pressurized structure in which vehicle maintenance can be carried out.

Predeparture Operations

Predeparture operations are of high importance. These activities will undoubtedly be rehearsed throughout the surface mission in simulations and training.

1. *Cleanup of the habitat.* The current Reference Mission scenario calls for a period of several weeks in which the habitat will be unoccupied before the next crew arrives.

2. *Trash disposal.* This topic raised considerable concern. On one hand, there will surely be trash. On the other hand, much of it may be reusable, and all of it was very expensive to bring to Mars. It was decided that it could be appropriate to construct an external shelter for the storage of trash.

3. *Systems would be placed in standby or turned off.* The biological life-support system will no doubt have quite special requirements for the period in which a crew would not be present.

4. *Verify ascent vehicle systems.*

5. *Load return cargo to ascent vehicle.*

6. *Transfer crew to ascent vehicle.*

7. *Leave the base for return to Earth.*

Little consideration was given to the day-to-day routine operations of the crew, such as those related to eating, sleeping, health maintenance, base housekeeping, and personal activities. These are likely to be similar in many ways to current activities in the space shuttle or planned for the space station. The one area of new interest that was discussed, though not in detail, is crew recreation. It is recognized that for missions that will last on the order of three years, relaxation from scientific, technical, or operational tasks will be important. Both individual and group recreational activities can be imagined. Some of the recreation will surely be electronic, consisting of information brought or sent from Earth, both of a public and private nature. Physical activity can be included in the exercise regime, and EVAs will require rigorous exercise, which may be therapeutic in itself. It has been suggested that capability be provided for recreational EVA. The advent of inflatable structures suggests that it may be possible to practically provide much greater space and larger volumes than have been common on previous space flights. This raises the possibility of developing Mars-gravity athletic games, such as handball, within a pressurized facility. It may be possible to develop intermediate types of facilities, pressurized with CO₂ gas, within which crew members would have to wear air masks, but not space suits, opening further possibilities.

VIGNETTES TO ELUCIDATE THE SURFACE MISSION

It was decided that a set of vignettes might be developed to illustrate some of the more important, interesting, or complex aspects of the surface mission, perhaps in video format. Two types of vignettes are developed in scanty detail in Table 2.

1. *Science-driven vignettes.* These are based on the important scientific and technical objectives of sending humans to Mars. These should convey the importance of the exploration as well as the importance of the human role in them. These will be of use in designing supporting equipment and infrastructure as well as explaining the values of the missions.

2. *Human interest, operational vignettes.* These are of interest in planning human activities, designing support systems, and understanding the time implications of various assumptions. These two areas to some extent are concurrent with the topics of the two working groups; however, there are areas of overlap.

NEXT STEPS AND RECOMMENDATIONS

The surface mission and activities identified by the attendees at the Mars Surface Mission Workshop obviously only touch the surface of the activities that should eventually

be planned for the martian surface. It is recommended that a process and program be put into place whereby a wide range of people can contribute to the thought process. This is a fruitful area for the development of university or even secondary education involvement in the Mars exploration program. It is an area where there is little current technical basis; the questions and activities are of high inherent interest, and the younger generation can expect that their representatives will be the ones who actually are able to do this exploration.

The surface mission should be the basis for developing a set of activities in conjunction with the planetary surface simulation facility at the Johnson Space Center. A workshop format is probably not the proper venue for making progress in this area; rather, a design program in which there is actual support for bright students and groups of students to learn about the capabilities of the Mars mission and design activities could stimulate much new thinking. It obviously would provide a new outreach mechanism for NASA as well.

TABLE 2. Science-driven activities.

Humans discover evidence for fossils on Mars.	Through a combination of incisive field work and the ability to microscopically examine the samples they collect, the crew geologist has located an outcrop that definitely shows evidence for fossils.
The composition of the atmosphere of Mars 3.8 b.y. ago is determined by the examination of fluid inclusions within salt crystals formed in a dried-out lake bed.	Collecting a short core sample, astronauts are able to identify a layer of large salt crystals that microscopically show tiny inclusions of fluid. These are analyzed in the outpost mass spectrometer.
Evidence for local hydrothermal alteration of rocks is found associated with melt rocks in the vicinity of a 100-m diameter impact crater, showing that ground ice existed at the time of the impact.	Field work on the floor of a fairly small impact crater shows evidence of hydrothermal alteration that formed when the ground ice melted and steam and water altered the surrounding rock.
Crew makes the final selection of rocks to be returned to Earth for analysis.	Over the period of the mission, the crew has collected over 50 tons of rocks, but can only bring 100 kg back to Earth. Which will they choose?
The first scientific debate on Mars.	Two crew members, observing the same set of features in the field, come to quite different conclusions as to how the features form. They decide that they can collect some additional samples that will settle the debate.
An ancient martian lakebed is confirmed.	The confirmation of the existence of a lakebed has been gained by a combination of morphological observations, including digging of trenches along the proposed shoreline and subsurface coring.
Subsurface water is found by geophysical techniques.	The seismic heat flow and radar sounding experiments all point to the existence of a layer of water or brine at a depth of 600 m. The next step will be to set up a drill to penetrate; however, great precautions will have to be taken to preserve cleanliness and protect the astronauts from contamination. In addition, the water may be pressurized.
The petrographer has put together the first representative suite of Mars highlands rocks.	Sampling an old stream bed, the geologists have collected a variety of samples. Cutting thin sections from them and studying in the microscope has revealed the range of rocks that formed over the first 2 b.y. of Mars evolution.

TABLE 3. Human interest-driven activities.

First crew arrives on Mars.	Crew lands, connects to power, assembles habitats, and raises flag.
Setting up the biological life support system.	Astronauts bring the inflatable to the site, erect it, carry in trays, tanks, and pipes; assemble the systems; plant, grow, and harvest crops; and have the first Mars Thanksgiving dinner.
Outpost setup (robotic).	Power system, radiators, and cables are deployed; ISRU system is set up; rovers are deployed; structure is inflated; and power is connected.
Astronauts raise weather balloon above base.	The balloon on a 1000-m tether contains H ₂ gas produced on Mars from its water. It carries a weather station as well as a 360° camera capability and a navigational beacon for surface operations.
Astronaut drives rover toward canyon wall.	Walls of the canyon display a stratigraphy that becomes increasingly clear as the pressurized habitat approaches. The cliff towers above the crew when they reach the bottom.
Crew health maintenance—treadmill, examination room, etc.	Crews will be under routine medical surveillance for the effects of long-term exposure to the Mars environment.
Crew meeting.	Discussing the recent activities, the crew decides that they will recommend a significant change to the exploration plan.
Crew recreation. Crew tests mountain-climbing capabilities in a nonthreatening environment.	Eventually, some crew member will want to go into a dangerous area, and there will be little that can be done to stop him/her. So, it is considered better to develop the technical needs of this activity in a local, nondangerous environment.
Building on Mars.	The crew uses blocks made of natural martian material to construct a sample storage shed.

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